THE UNIVERSITY OF TEXAS BULLETIN
No. 3645: December 1, 1936

A STUDY OF MOTOR OILS SOLD IN TEXAS AND REVIEW OF MOTOR OIL SPECIFICATIONS

By

DAVID McKNIGHT, JR., M.S. in Ch.E.
Ceramic Engineer; Secretary of the
Bureau of Industrial Chemistry

and

ROBERT ELMO PRICE, M.A.

Bureau of Industrial Chemistry
E. P. Schoch, Director

Division of Conservation and Development
of the Natural Resources of Texas

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of Democracy, and while guided and controlled by virtue, the noblest attribute of man. It is the only dictator that freemen acknowledge, and the only security which freemen desire.

Mirabeau B. Lamar

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INTRODUCTION

The study reported in the following pages was undertaken by the Bureau of Industrial Chemistry under the direction of Dr. E. P. Schoch. The work was done by a group of graduate students in the University comprising Messrs. Quintus Cato, Henry L. Dabney, Ruben F. Pfennig, Robert E. Price, Jack Steele, and Elmer H. Timmerman, under the supervision of the writer. Upon the completion of the work, Mr. Price prepared a report which has been found to be so complete that it is used with very few changes as the text of this bulletin.

This study of motor oils was undertaken for the purpose of determining the relative merits of oils sold in Texas. Unfortunately, it is impossible to publish, in a report such as this, the names of products tested. The prevalence of unsatisfactory oils on the market gives rise to a very serious question as to just what can be done to protect the buyer from products which do not properly meet his needs. This study shows that he can be much more certain of getting his money's worth if he buys the higher priced oils, and if he buys only canned oils. But even with these guides he is not perfectly safe. And what is the man to do to whom 30-cent oil is an expensive luxury? And, in view of the fact that there are some satisfactory oils in the lower price ranges, why make the dealer in these oils suffer from the stigma of selling a cheap oil?

In a previous report dealing with a similar study of gasolines the writer suggested "that some legal restrictions may be placed on the industry which will require a dealer to display a truthful statement of the quality of the gasoline he offers for sale." Although experience has shown that it is difficult to remedy such situations by law, a similar observation might well be made with regard to lubricating oil.

Since it has long been evident that the quality of lubricating oil is determined not only by its properties as sold but

by the changes in its properties as it is used, many attempts have been made to test the stability of oils. None of these tests has as yet become standard, and a study of the various tests was made in planning this work. It was finally decided to employ what is known as the Indiana Oxidation test, and the necessary apparatus was accordingly constructed in this laboratory. Mr. Price describes the test and the apparatus in some detail in his report. At this point suffice it to say that the construction of this equipment was no small task in itself, and was very capably done by Mr. Price and Mr. Pfennig, with the assistance of Messrs. W. L. Benson and Harry Williams, mechanics in the Department of Chemistry.

In a preface, not reprinted here, Mr. Price takes occasion to acknowledge the work of the coworkers and mechanics above mentioned. He also expresses appreciation for the help and advice received from Dr. E. P. Schoch, and from Mr. G. T. Hamblen.

DAVID MCKNIGHT, JR.

DESCRIPTION OF LABORATORY PROCEDURE

SAMPLING

Samples of every kind of motor oil known to be sold in Austin, Texas, were bought during the first half of December, 1935. Whenever possible, three grades, corresponding to SAE numbers 20, 30 and 40, were obtained for each brand of oil sampled. In only a few instances all three grades were not available. In order to obtain additional samples, a trip was made to Houston during the second week in January, 1936, and other samples acquired then. While the majority of the samples were obtained from retail service stations, it was necessary to visit wholesale warehouses to obtain samples of some of the cheaper oils whose sales are seasonal.

Each sample was designated by a number and a letter—the number denoting the brand of oil, and the letter the SAE rating. Oils corresponding to SAE 20 bear the letter *a;* SAE 30, *b;* and SAE 40, *c.* For example, samples numbered 13a, 13b, and 13c are all samples of the same motor oil with ratings of SAE 20, SAE 30 and SAE 40, respectively. A record of the cost per quart and the place and time of purchase was made for each sample.

Most of the laboratory tests to which samples were subjected in this study were made in accordance with the standards of the American Society for Testing Materials. In the case of corrosion and oxidation tests, no test has as yet been adopted as standard by this body. The oils were subjected to the corrosion test specified by the Federal Specifications Board. The oxidation test developed in the laboratories of the Standard Oil Company of Indiana was used. The details regarding both apparatus and procedure for the other tests may be found in *A.S.T.M. Standards on Petroleum Products and Lubricants*, issued in September, 1935.

Gravity

The gravity, an expression denoting weight per unit volume, was determined by the use of the Westphal balance, an instrument which measures the bouyancy exerted by the liquid upon a plummet of known displacement. From the specific gravity thus obtained, the gravity was calculated in degrees on the A.P.I. scale, the usual method for expressing the gravity of petroleum products in the United States. The mathematical relation connecting specific gravity with "degrees A.P.I." is:

$$^{\circ}\text{API} = \frac{141.5}{\text{Sp. Gr. } 60^{\circ}\text{ F.}/60^{\circ}\text{ F.}} - 131.5$$

Corrosion

To test for the presence of corrosive substances in the sample of oil, a strip of freshly polished copper is placed in a test-tube and covered with the sample to be tested. The temperature of the test-tube is maintained at 212° F. for a period of three hours by immersion in boiling water. If, upon examination, the copper is not found to be seriously discolored or pitted, the oil is considered to be free from corrosive compounds (a negative test). In the event that discoloration or pitting has occurred, the test is reported as positive.[1]

Color

The procedure given in ASTM Designation D 155–34T[2] is followed in determining the colors of the oils by use of the ASTM Union Colorimeter. The color of a sample of oil by transmitted light is compared in the colorimeter with the color of glass standards and is reported by the number of the glass standard most nearly corresponding. In the

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[1]Federal Standard Stock Catalogue, Sec. IV, VV–0–496, Method 530.31.

[2]*ASTM Standards on Petroleum Products and Lubricants*, pp. 54–58.

case of extremely dark oils, dilution with benzene before comparison is necessary. The color is reported as the number of the standard most nearly corresponding to the diluted sample, this number being followed by a *D* to denote the dilution.

Neutralization Number

The procedure described in ASTM Designation D 188–27T[3] is followed in the determination of the neutralization number of the sample of oil. A weighed sample of oil is agitated with aqueous ethyl alcohol to extract the acidic components of the oil, which are then titrated using phenolphthalein as an indicator. The neutralization number is the number of milligrams of potassium hydroxide necessary to neutralize one gram of oil.

Conradson Carbon Residue

In accordance with the directions given in ASTM Designation D 189–30,[4] the sample of oil to be tested is placed in a weighed porcelain crucible which is then surrounded by two iron crucibles and an iron hood to exclude the air from the oil as it is heated. After all the volatile components have been expelled by heating at the specified rate, a carbonaceous residue covers the porcelain crucible. This residue, expressed as a percentage of the sample taken, is called the Conradson carbon residue.

Flash and Fire Points

ASTM Designation D 92–33[5] describes the procedure to be used for this test. A sample of oil is heated in a special brass cup so that its temperature rises from 9 to 11° F. per minute. At each interval of 5° F., a small flame is passed over the rim of the cup. The temperature at which the oil vapors are being evolved with sufficient rapidity to

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[3] *Ibid.*, pp. 210–212.
[4] *Ibid.*, pp. 43–46.
[5] *Ibid.*, pp. 115–119.

form an inflammable mixture with the air, as evidenced by a flash when the test flame is applied, is called the flash point. Heating at the specified rate is continued and the test flame applied until the oil vapors are of sufficient concentration to continue burning after removal of the test flame. The temperature at which this occurs is called the fire point.

Cloud and Pour Points

The procedure and apparatus for this test is described in ASTM Designation D 97–34.[6] In order to determine the cloud point of an oil, about an ounce is placed in a test jar and placed in the cooling bath. As the temperature of the oil decreases, the sample is observed every 2° F. decrease to see if the wax has begun to solidify. The temperature at which the wax has crystallized sufficiently to cause the oil to have a cloudy appearance is called the cloud point of the sample.

The pour point of an oil is determined in a similar manner. As the oil cools, it is observed every 5° F. until it is found to be so congealed that it will not move when the test bottle is held in a horizontal position for 5 seconds. The pour point is defined as 5° F. above the temperature at which congelation occurs.

Viscosity

The method used in making this test is described in ASTM Designation D 88–33.[7] The sample tested is placed in the oil tube of the viscosimeter and allowed to reach the temperature of the determination. The viscosity of the oil is reported as the number of seconds for a 60 cc. portion to flow, under its own head, through the small orifice in the bottom of the oil tube. Viscosity determinations were made at 100° F. and 210° F., and the viscosity at 130° F.

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[6] *Ibid.*, pp. 47–53.

[7] *Ibid.*, pp. 298–303.

was then calculated from the ASTM Viscosity-Temperature Chart (Designation D 341–32T).[8]

Indiana Oxidation Test

The oxidation test employed in this investigation is that devised by the Standard Oil Company of Indiana.[9] However, slight modifications in procedure were necessary to handle the large number of samples to be tested. It is the opinion of the writer that these variations from the procedure specified by those who originated the test affect the results only slightly, if at all. Any variations in the results which might have been occasioned by deviations from the prescribed procedure are uniform; therefore, no error is incurred in comparing the merits of the various samples on the basis of these results.

A 300 cc. sample of oil to be tested is placed in a large Pyrex test tube, 50 cm. long and 45–50 mm. inside diameter, which is immersed in an oil bath to a depth of about 30 cm. The oil bath used, which accommodates 24 samples, is maintained at a constant temperature of 172° C. by means of electric heaters and a motor-driven stirrer. Air is supplied to each of the test tubes at the rate of 20 liters per hour, measured at laboratory conditions, through capillary chokes connected to a manifold. The air delivery tubes extend to the bottom of the test tubes so that the stirring action of the rising air bubbles will prevent the sludge settling to the bottom.

After the samples have been allowed time to reach the proper temperature, the air is turned on. At 24-hour intervals samples are withdrawn with a pipette and weighed into a tared 250 cc. Erlenmeyer flask until 3 such samples have been taken. The weight of the sample taken in each case is 10 grams, ± 0.1 gram. Each sample is then diluted

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[8] *Ibid.*, pp. 310–313. The chart used was an enlargement of this plot.

[9] Rogers, T. H. and Shoemaker, B. H.: "Indiana Oxidation Test for Motor Oils," *Industrial and Engineering Chemistry*, Analytical Edition, *6*, 419 (1934).

with 100 cc. of ASTM precipitation naphtha and allowed to stand for 3 hours at room temperature before being filtered through a weighed Gooch crucible. After filtration the residue and crucible are washed with additional naphtha to remove any traces of oil that might remain. After being dried in an electric oven at 150° C. for 30 minutes, the crucible is reweighed. The increase in weight is taken as the weight of asphaltenes formed and is expressed as milligrams of asphaltenes per 10 grams of oil. At the end of 50 hours, a 100 cc. sample is withdrawn for viscosity determinations. These viscosity determinations were made at a temperature of 210° F. Rogers and Shoemaker state that this portion is to be returned to the test tube immediately after the viscosity determination has been completed,[9] but since it was impossible to determine the viscosity of 24 samples immediately, this portion was discarded. There is no apparent reason why this deviation from the procedure suggested by Rogers and Shoemaker should invalidate the results by increasing the rate of oxidation since an excess of air is provided even at the start of the test. As previously mentioned, each of the samples was handled similarly, so the results thus obtained should provide a sound basis for comparisons.

The chokes for regulating the flow of air were made by collapsing a short piece of capillary tubing around a strand of No. 30 (B&S gage) wire and immersing the capillary in nitric acid until the wire had been dissolved. This procedure should give chokes of uniform bore, but, as an additional check, each choke was individually calibrated by means of a wet-test gas meter. In order that changes of the oil level in the test tubes would not materially affect the rate of air flow, it was arranged to have nearly all of the pressure drop in the entire system across the choke. A pressure of 2 inches of mercury above atmospheric pressure was maintained in the manifold at all times during the tests.

To insure constant temperature of the oil bath, a thermostat of the bimetallic-helix type was included in the

circuit of one of the heaters. It was observed, however, that the heat output of the heaters were such as to maintain the proper temperature without this control.

For comparative purposes, it was deemed advisable, in this case, to compare amounts of asphaltenes formed in a given time rather than to compare times required to form a given amount of asphaltenes as suggested by Rogers and Shoemaker, since the former values may be determined directly while the latter require interpolation on plotted curves.

SIGNIFICANCE AND INTERRELATIONS OF LABORATORY TESTS

GRAVITY

For some time authorities have considered the determination of the gravity of an oil to be of little value as an indication of the lubricating qualities to be expected. This determination was chiefly utilized as a method of identification. For a given viscosity range, the oils having the higher API gravities—that is, lower specific gravities—are the more paraffinic in nature. It will be noted that these oils also exhibit higher flash points, higher viscosity indices, higher Conradson carbon residues, and higher pour points; however, by means of certain improved refining methods now employed, the latter two properties can be varied materially without effecting a change in the gravity of the product. The results of this investigation indicate that there is a definite relationship existing between the gravity of a motor oil and its resistance to oxidation. A more adequate consideration of the importance of gravity determination as an indication of resistance to oxidation is embodied in the discussion of the significance of the Indiana oxidation test.

CORROSION

While the copper strip corrosion test is used to detect the presence of harmful constituents in a new oil, it is the writer's opinion that the injurious effects on the engine due to the small amounts of corrosive material indicated by a positive corrosion test are far less than those resulting from other causes; for example, abrasion of the moving parts by dust particles and other solids carried by the oil stream. It is a well established fact that the acidity of crankcase lubricants increases materially during operation. While most of the acidic components are harmless fatty acids of high molecular weights and naphthenic acids,

harmful sulfur acids also have been encountered.[10] It is possible that these develop during use from sulfur compounds that were undetected by the copper strip test in the new oil, since all sulfur compounds are not corrosive to copper. Thus, while the corrosion test is very sensitive, the results are not of extreme importance.

Color

The color of a sample of motor oil does not necessarily offer any indication of its quality. However, oils that possess a very light color are usually more highly refined than darker oils. While fluorescence is a property of the better oils, many cheap oils have been given a highly fluorescent appearance by the addition of organic dyes. These added substances improve the appearance only and do not affect the value of the oil as a lubricant.

Neutralization Number

The neutralization number, the number of milligrams of potassium hydroxide required to neutralize one gram of oil, is intended to give an indication of the acidic components of an oil. The procedure that is usually followed in making these determinations represents not only the mineral acids that may be present due to improper washing after acid treatment in the refining process, but the harmless organic acids as well. There is some argument that the presence of a small amount of organic acidity is of actual value in increasing the lubricating ability of the oil, but the data to support this belief is not absolutely definite. The results of the determination of the neutralization number of oils is almost without value since an oil with a very low neutralization number due to the presence of small quantities of mineral acids would be far more deleterious in effects than an oil having a high neutralization number due entirely to harmless organic acids. Of

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[10]Dietrich, M. A.: "Service Changes in Crankcase Lubricating Oils," A.S.T.M. *Symposium on Motor Lubricants*, 1933, p. 72.

course, an extremely low neutralization number is indicative of freedom from acidic components of either type.

Conradson Carbon Residue

The Conradson carbon residue test was designed to give a method for comparing the tendencies of various motor oils to deposit carbon in an internal combustion engine. Investigators offer data to confirm the view that the Conradson carbon residue of an oil is an approximate indication of the tendency to deposit carbon in an automobile engine, all other controlling factors maintained constant.[11] While these deposits are constantly referred to as "carbon" deposits, they contain very little, if any, chemically uncombined carbon. Gruse reports that these deposits contain a portion of unchanged oil, an intermediate coke-like portion, and mineral matter which appears as ash.[12]

Some of the more important factors in determining the rate of formation of carbonaceous deposits in gasoline-powered engines are: Engine design and operating conditions, running conditions, oil consumption, dust in the air, air-fuel ratio used, characteristics of the fuel, and characteristics of the lubricating oil. Since a complete discussion of all these factors is beyond the scope of this study, this discussion will be limited to the effect of the characteristics of the lubricating oil on the formation of engine deposits. A comprehensive study of carbon deposits, conducted under the supervision of W. A. Gruse at the Mellon Institute of Industrial Research, Pittsburgh, Pennsylvania, is available.[12]

In considering the influence of motor oils on the formation of engine deposits, it is necessary to assume that the other controlling factors are to be maintained constant.

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[11]Livingstone, C. L., Morley, S. P., and Gruse, W. A.: "Motor Carbon Deposits Formed Under Controlled Conditions from Typical Automobile Oils," *Industrial and Engineering Chemistry, 18,* 502 (1926).

[12]Gruse, W. A.: "Carbon Deposits in Gasoline Engines," *Symposium on Motor Lubricants,* p. 9.

The two possible mechanisms for the phenomenon of the deposition of carbon recognized by Gruse are: (1) The cracking of the oil to coke, and (2) the oxidation of the oil to materials which eventually produce coke. However, he is of the opinion that little oxidation occurs normally.

> In the combustion chamber the oil is sprayed up rather violently; some of it stays in the gas space, is burned, oxidized or coked, and the products pass out with the exhaust. The fate of these products is of no importance unless they stick to the exhaust valve or stem. The oil which hits the metal surfaces is more important. If it is volatile at the metal temperature (exposed to periodic flames), it will distil away nearly completely before much can happen to it. If it is completely non-volatile under these conditions there is a possibility that it will cause trouble. The oxygen content of the chamber rises periodically to a little less than 19 per cent, but it is always mixed with oxidizable gasoline vapor, usually in excess, and during the greater part of the time, the oxygen content of the system is very low. Furthermore, the oil is protected by a layer of its own rising vapor. In other words, little or no oxidation in the combustion chamber need be expected. But the oil is on a hot surface and it is being broiled by a periodic flame, thus effecting what is essentially a coking distillation. Under these conditions, the amount of deposit would seem to depend on: (1) the amount of residue not volatile at the prevailing temperature; (2) the amount of coke formed from this residue; and (3) the degree of adherence of this coke.
>
> The amount of residue left on the walls seems entirely a matter of boiling point. The nature of this residue and the products from it are of considerable significance. If it contains an appreciable content of resins which yield coke, or if it forms much coke itself in cracking, and if, furthermore, the coke formed is adherent, the conditions for a troublesome deposit are present.[13]

Experiments conducted in the laboratory of The Texas Company, Bayonne, New Jersey, in which carbon-dioxide-free hydrogen was used as a fuel in a single cylinder research engine, showed the presence of considerable carbon dioxide in the exhaust gases, traceable to the oxidation of

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[13]*Ibid.*, pp. 15–16.

the lubricating oil used. When excess air was used in the combustion of the motor fuel, which is the case in actual motor operation, an average carbon dioxide concentration, according to an Orsat analysis of the exhaust gases, was 0.30 per cent. This value increased with the viscosity of the lubricating oil used, and decreased when an oil of lower viscosity was used. Minter and Finn offer this explanation:

> An oil of low viscosity shows less burning than an oil of high viscosity doubtless because less of the former gets into the cylinders on account of the formation of a thinner film on the cylinder walls, with less accumulation on top of the piston.[14]

They report that, when the hydrogen was in slight excess in the exhaust gases, the oxidation of the lubricating oil, as evidenced by only traces of carbon dioxide in an analysis of the products of combustion, was negligible.

Minter and Finn make this further observation:

> It was observed that the temperature of the exhaust when running the engine on hydrogen was about 100° C. lower than when running with gasoline. For this reason, it is possible that slightly more lubricating oil would be burned when operating with gasoline because the oil film in the cylinder would be exposed to higher temperatures.[14]

T. H. Rogers, Assistant Director of Research, Standard Oil Company of Indiana, is not willing to discard as impossible the theory that some coke formation may be due to oxidation, but admits that, regardless of whether the coke is formed by oxidation or by thermal decomposition, volatility tests should provide a satisfactory method of predicting engine carbon formation, since such tests would give an indication as to the relative amounts of unvaporized oil remaining on the piston head.[15]

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[14]Minter, Clarke C. and Finn, William J.: "Amount of Lubricating Oil Burned in a Gasoline Engine," *Industrial and Engineering Chemistry, 23,* 285 (1931).

[15]*Symposium on Motor Lubricants,* p. 23

> In certain cases a correlation between Conradson carbon residue and engine (residue) would be expected but this is only because in these cases the Conradson carbon test correlates roughly with volatility pointed out by Mr. Gruse. The Conradson test is a race between vaporization and coking. Accordingly, oils of equal degree of refining from any one crude will give Conradson carbon values roughly in line with volatility. With oils from various crude oils or with varying degrees of refining the Conradson test results are not a measure of relative volatilities. Thus only in those cases where the relative Conradson values are a measure of relative volatilities do we find a correlation between Conradson carbon and engine carbon.
>
> We feel that the volatility test is by far the most accurate correlation which has so far been proposed and the soundness of it has been tested and proved through the use of the widest variety of lubricants so far attempted.

Despite these and other objections to the Conradson carbon test, other evidences obtained from a study of paraffinic, naphthenic, and hydrogenated lubricating oils with full-size engines, indicate that, generally speaking, deposits from these three classes of oils were proportional to the carbon residues.[12]

Livingston, Morley, and Gruse offer experimental data which indicate that the motor oils from Pennsylvania and Midcontinent crudes give total carbon deposits far greater than oils from Gulf Coastal crudes.[16] This finding is in line with the opinions of Rogers since the Coastal oils are more volatile than either the Pennsylvania or Midcontinent oils. The three investigators just mentioned also observe that the deposits from Coastal oils not only contain less oily matter, but are more easily removed from the engine than the deposits from the more paraffinic oils.

By extensive refining it is possible to produce a motor oil that is highly paraffinic in nature (as indicated by a high API gravity, high flash point, high viscosity index,

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[16]Livingstone, C. L., Morley, S. P., and Gruse, W. A.: 'Motor Carbon Deposits Formed Under Controlled Conditions from Typical Automobile Oils," *Industrial and Engineering Chemistry, 18,* 502 (1926).

and high resistance to oxidation) that leaves practically no residue in the Conradson test. Samples 7a, 9a, 11a, 7b, 9b, 11b, 7c, 9c, and 11c included in this study are examples of such achievement.

Gruse concludes by saying:

> It is indicated that if an engine without an air-cleaner runs cool on a rich air-fuel mixture with a high oil consumption, the oil being one of high carbon residue value, the engine will very probably encounter a great deal of trouble traceable to carbon deposits. The opposite conditions, dust-free air, a hot-running engine with a lean air-fuel mixture, and low consumption of an oil of low carbon residue value, will very probably induce freedom from excessive deposits. Obviously, the cars on the road present all the permutations of all the shades of interval of all these conditions. As regards the lubricating oil itself, this study suggests the desirability of hastening the day when the average motor car can use, with tolerably low consumption, oils of lower viscosity than the present SAE 40 and 50 grades. The adoption of such less viscous lubricants is probably the simplest means of remedying some of the troubles and securing some of the advantages discussed above.[12]

Even though a majority of the investigators are convinced that the Conradson carbon residue is, at the best, only a rough approximation of the tendency of an oil to form carbonaceous deposits in the combustion chamber of an engine, it is thought that, by using an oil with a low carbon residue and as low viscosity as economical operation will permit, no serious trouble from carbon deposits should be encountered during the course of normal operation of an automobile that is in at least fair mechanical condition.

Flash and Fire Points

The flash point determination for petroleum products was originally designed to indicate fire hazard. Its application in the testing of motor oils is of a different nature. The chief value of flash point tests in the case of motor oils is as a method of identification and classification. Oils

of the same viscosity range refined from paraffin-base crudes have noticeably higher flash points than do those refined from asphaltic crudes; however, more reliable and accurate methods of differentiation of type of oil are available, such as gravity and refractive index. An extremely low flash point indicates the presence of volatile diluents, possibly the higher-boiling fractions of gasoline or kerosene. Oils, purchased in the bulk and which show extremely low flash points (below 300° F.), are to be suspected as being crankcase drainings with very little, if any, lubricating value without a complete re-refining operation. The presence of small amounts of water in a sample is detected easily by foaming and popping in the course of a flash point determination. The flash point of an oil offers some indication of the tendency of an oil to vaporize, but tells nothing in regard to the relative amounts of material volatile at any given temperature.

ASTM Committee D–2 on Petroleum Products and Lubricants has this to say concerning the flash point of a lubricating oil:

> The usual practice in writing specifications is to attempt to identify certain types of oils which are known through experience to be suitable. Existing methods for determining the actual usefulness or value in lubricating oils are not satisfactory and in general it may be stated that the use of flash point limits in lubricating oil specifications is actually a makeshift to compensate for a large factor of ignorance.[17]

The information given by a fire point determination adds little to that obtained by a flash point. It was found in this study that for a majority of the samples tested that the fire point is about 40 to 60° F. above the flash point. This interval becomes less for oils having lower flash points.

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[17]ASTM Committee D–2 on Petroleum Products and Lubricants: *The Significance of Tests of Petroleum Products*, p. 54.

Cloud and Pour Points

As petroleum oils are cooled they tend to become more or less plastic solids. This may be due either to the partial separation and solidification of the wax present or actual congelation of the heavy hydrocarbons composing the oil. When the cooling is carried out under certain prescribed conditions, the temperature at which enough wax has crystallized to give the oil a cloudy appearance is called the cloud point. The chief value of a cloud point determination is as an indication of the completeness of the dewaxing process. An oil having a high cloud point has obviously been dewaxed less than one having a very low cloud point. It must be admitted, however, that the cloud point is less significant and of more limited application than is the pour point.

The pour point test was designed to indicate the lowest temperature at which an oil, when cooled at a given rate, will remain fluid. ASTM Committee D–2 on Petroleum Products and Lubricants offer this comment on the results of the pour point determination:

> The pour point gives an indication of the temperature below which it may not be possible to pour or remove an oil from its container, or below which it might be dangerous to use the oil in gravity lubricating systems, where the head tending to produce flow is small. However, it should be borne in mind that the size and shape of the container, the head or force exerted upon the oil, and the nature of its physical structure when solidified, all have an effect upon its tendency to flow.[18]

Under lower rates of cooling than that employed in the ASTM pour point determination, oils have been pumped at temperatures from 10 to 15° F. below the determined pour points. It is indicated that the pumpability of an oil at low

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[18]*Ibid.*, p. 9.

temperature is limited more by viscosity than by the pour point.[19]

In the article just referred to, J. L. McCloud, Metallurgical Chemist for the Ford Motor Company, quotes A. E. Becker[20] quite freely. Becker finds that, if oils having a pour point of 0° F. or lower are considered, the time required for a pump to deliver oil to the bearings is proportional to the viscosity of the oil at the pumping temperature. Becker further observed that oils below their pour points require considerably longer to establish circulation than those above their pour points.

Evidence has been submitted to show that the presence of wax in oil, even when the temperature is above the determined pour point, is another important factor in determining the readiness with which an oil may be pumped[19]

It was first supposed that the pour point of a motor oil was a controlling factor in determining the ease of starting. This supposition was based upon a seemingly natural assumption that less force would be required for movement through a liquid than through a solid, even though the solid was plastic in nature. The fallacy of this idea was demonstrated by the fact that a low-pour-point asphaltic-base oil required greater starting torque than did a medium-pour-point paraffin-base oil. The oils were of the same viscosity at 210° F., but at the temperature of the experiment, the viscosity of the asphaltic-base oil was considerably higher than that of the paraffin-base oil. It is now generally thought that the viscosity of the oil remaining on the cylinder walls is the prime factor in determining the ease with which an engine may be started under conditions of low temperature. In order to facilitate starting in cold weather, it is recommended by some to stop the engine by

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[19]McCloud, J. L.: "Present Concepts of the Relation of ASTM Pour Test to Service Requirements of Oils," *Symposium on Motor Lubricants*, p. 33.

[20]A. E. Becker and W. C. Bauer, *Oil and Gas Jour. 28*, No. 40 p. 46 (1930).

A. E. Becker, *Automotive Industries, 46*, 401 (1931).

use of the choke rather than the ignition switch. The viscosity of the oil inside the cylinders is greatly reduced by the raw gasoline without resulting in serious crankcase dilution.

The oil in the bearings exerts only a small influence, if any, on the ease of starting experienced. This is entirely congruous with what would be expected, since the bearing surface involved is negligible in comparison with the surface of the cylinder walls.

While the ease of starting under conditions of low temperature is highly important, A. E. Becker is of the opinion that the lubrication of the engine during and immediately after starting is of major importance.[21] In regard to lubrication during the initial period of operation when the oil is highly viscous, J. C. Geniesse, Research Engineer of the Atlantic Refining Company, offers this comment:

> As a result of the lack of proper lubrication undue wear takes place on the cylinder walls and pistons. Obviously, it is difficult to determine the amount of wear that takes place during the warming up of the motor, but it is reasonable to estimate that from 50 to 75 per cent of the wear takes place during this period.[22]

This consideration serves to emphasize further the importance of selecting an oil that will not only permit easy starting at low temperatures, but will require a minimum time to establish full lubrication of all the moving parts of the engine. Evidence has been submitted to indicate that both a low pour point and a low viscosity are important properties of a lubricant to be employed in low temperature lubrication. Although a low cloud point is desirable, it is of less importance than either a low pour point or low viscosity.

Viscosity

Viscosity has long been considered as one of the most important properties of lubricating oils. Not only does the

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[21]*Symposium on Motor Lubricants*, p. 47.
[22]*Ibid.*, p. 48.

measurement of viscosity provide a satisfactory method of classification, but it has been proved that a definite viscosity range is a service requirement. An oil of low viscosity at low temperatures is highly desirable to assure easy starting and establishment of proper lubrication in a minimum time, but it is equally important that the oil be sufficiently viscous at engine temperatures to maintain a fluid film between the rubbing surfaces of the engine. The best petroleum oils available are far from ideal in this respect; in fact, the viscosity invariably decreases with increased temperature.

Some oils have viscosity-temperature relations far superior to others, determined by the base of the oil and the refining methods employed. One of the most satisfactory means that has yet been presented for describing quantitatively the variations of viscosity with changes in temperature was developed by Dean and Davis. These two investigators made a detailed study of the viscosity-temperature relations of two oils chosen as standards, one of which showed a maximum change in viscosity from 100 to 210° F., and the other, a minimum change over the same temperature range. To the oil which showed maximum variation in viscosity was assigned a *viscosity index* of 0; to that showing minimum variation, a *viscosity index* of 100. By means of a formula given by Dean and Davis, it is possible to calculate the viscosity index of an oil after determination of its Saybolt Universal Viscosity at 100° F. and 210° F.[23]

Since the development of the viscosity index as an expression of the change in the viscosity of an oil with temperature, improvements in refining processes have produced oils which show less variation in viscosity than did the oil chosen by Dean and Davis as the upper standard. The viscosity indices of such oils are expressed by numbers greater than 100. There are some motor oils on the market

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[23]Dean, E. W., and Davis, G. H. B.: "Viscosity Variations of Oil with Temperature," *Chemical and Metallurgical Engineering, 36,* 618 (1929).

which show more variation in viscosity than did the oil taken as the poorer standard. To these oils negative numbers are assigned as viscosity indices.

From the discussion of the effect of viscosity on low temperature operation, it is manifest that an oil must have a low viscosity at low temperatures to assure easy starting and to establish proper lubrication promptly. Of equal importance is the requirement that the oil be of sufficient viscosity at normal engine temperatures to maintain a fluid film between the moving parts of the engine, particularly between the bearing surfaces. The load which a bearing can safely carry is limited by the viscosity of the lubricating oil at the operating temperature.[24] In order to provide a considerable safety factor which would permit the bearings to withstand occasional overloads, it is desirable that the viscosity of the oil be somewhat greater than is actually needed to maintain conditions of fluid film lubrication.

The advantage to be gained by the provision of such a safety factor is not available except at the expense of increased friction due to increased viscosity of the lubricant. An indication of the magnitude of this increase in friction may be gained from a report of E. W. Upham, Chief Metallurgist of the Chrysler Corporation:

> A further evidence of increased friction with increase in viscosity was obtained in a series of dynamometer test runs in the Chrysler Engineering Laboratories, on a 6-cylinder bus engine. The engine was run under full loads at speeds varying from 600 to 3400 r.p.m. Temperatures of main bearings were obtained under varying conditions of water temperature, oil temperature, oil pressure, and oil viscosity. Two oils of the same trade name corresponding to SAE No. 30 and SAE No. 50 were compared, with the water temperature held at 150° F., and the oil temperature at the header held constant at 200° F. With SAE No. 50 oil in the crankcase, the difference between the bearing

[24]Summary of a paper given by Sherman W. Bushnell, *SAE Journal, 36*, No. 2, 42 (1935).

> temperature and the header temperature was 9 to 10° F. greater than with the SAE No. 30 oil.[25]

Obviously, this added frictional drag imposed by the excessive viscosity of the oil increases the fuel consumption of the engine. Results of a series of tests on several makes of passenger cars, conducted at the Indianapolis Speedway, show that a decrease of 6.4 per cent in gasoline consumption was realized merely by changing from an oil corresponding to SAE No. 60 to one corresponding to SAE No. 30, other factors remaining the same. It must be admitted that oil consumption increases slightly with decreasing viscosity, but the findings of the investigation just cited indicate that the cost of the additional oil required was less than the saving in fuel consumption. Graves, Mougey, and Upham observe that:

> The lower-viscosity oils do not give as many miles per gallon of oil as do the higher-viscosity oils, but the difference in oil consumption, due to viscosity (differences), is not as great as many people believe.
>
> . . . The lower-viscosity oils, on account of causing less friction, will give more miles per gallon of gasoline, and the total cost of oil plus gasoline is usually less with low-viscosity oils than with high-viscosity oils.[26]

Graves[26a] concludes that the effects of both engine design and operating speed on the amount of oil used are far more pronounced than the effects of viscosity.

In the past, one of the general practices of the motoring public has been to use oil of rather high viscosity to cushion bearings and pistons against reciprocating loads in an effort to reduce engine noise. The price paid for this quieter

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[25]Upham, E. W.: "Viscosity of Automobile Crankcase Oils as Related to Service Requirements," *Symposium on Motor Lubricants*, p. 42.

[26]Graves, W. H., Mougey, H. C., and Upham, E. W.: "Winter Oils for Automobile Engines," *SAE Journal, 34*, No. 1, 247 (1934).

[26a]Graves, W. H.: "Oil Consumption in Motor Car Engines," *Symposium on Motor Lubricants*, pp. 85–100.

operation is increased gasoline consumption and narrowed range of temperature for satisfactory operation.

From the various considerations that have been offered, it will be seen that the ideal lubricating oil would be one which maintains practically the same viscosity at all temperatures. Since the possibility of the attainment of this ideal is extremely remote, if existent, the importance of using an oil which undergoes a minimum change in viscosity over the operating temperature range—that is, an oil with a high viscosity index—cannot be over-emphasized. In view of the fact that the use of oils of excessive viscosities definitely contributes to increased friction, which is accompanied by increased fuel consumption and higher bearing temperatures, there is a decided tendency toward using oils of low viscosity in an attempt to realize the most economical operating conditions.

Indiana Oxidation Test

The Indiana oxidation test is one of the most recent contributions to the field of testing lubricating oils. It was designed with a view to giving an accurate indication of the ability of an oil to resist the conditions conducive to oxidation encountered in the operation of an automobile engine. The importance of such a test for motor oils has long been recognized, but considerable difficulty was experienced in the development of a test that is satisfactory not only from the standpoint of accurate reproducibility but also from the standpoint of giving results that may be readily correlated with results from actual engine operation. Evidence has been submitted which indicates that even with different apparatus and different operators the results of this test are easily reproducible within a range of 10 per cent ($\pm$ 5%),[9] and that there is a straight-line relationship existing between results obtained from the

laboratory test and the results obtained from test engine operation.[27]

Undoubtedly the most deleterious result of oxidation of a motor oil is the formation of sludge. This formation of sludge is accompanied by a darkening in color and usually an increase in viscosity. In actual engine service this increase due to sludging is not detectable because of the decrease in viscosity caused by dilution of the crankcase lubricant with the unburned fuel. The presence of any appreciable quantity of sludge in the crankcase oil creates danger of clogged oil screens, oil lines, bearing grooves, and piston rings, resulting not only in excessive engine wear, but also bearing failures and scored pistons or cylinder walls in extreme cases.

In regard to some of the effects of sludge on engine operation, A. J. Blackwood offers this comment:

> Sludge is more dangerous in cold-weather operation than in warm-weather operation, and for cold operation, the importance of selecting a quality non-sludging oil cannot be overestimated. If sludge occurs in hot operation, it does one of two things, depending upon the nature of the oil and the engine operating conditions. First, it may stay suspended in the oil to give it a black color, in which case the oxidized materials are circulated with the oil. These materials are further oxidized in the ring zone to give, ultimately, ring sticking and are centrifuged in drilled crankshafts and bearings to completely clog the oil lines occasionally. Second, the sludge may settle out of the oil to form deposits in the crankcase. This has one questionable advantage in that, if the material settles out of the oil, less oxidized material will be circulating through the engine to give the troubles enumerated. It has been my experience that, when sludge settles out in the crankcase, the operator rarely has trouble with sticking rings and burned bearings; whereas, when bearings burn out or pistons score or have stuck rings, there are usually no excessive sludge deposits in the crankcase, except where water is present in the oil.[28]

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[27]Barnard, D. P., Barnard, E. R., Rogers, T. H., Shoemaker, B. H., and Wilkin, R. E.: "Causes and Effects of Sludge Formation in Motor Oils," *SAE Journal, 34,* No. 5, 167–178 (1934).

[28]Blackwood, A. J.: "The Performance of Engines at Low Operating Temperature," *SAE Journal, 36,* No. 2, 71–74 (1935).

The presence of any water in the crankcase augments the harmful effects of oxidation products by forming pasty emulsions which serve as binders for dust particles, carbon particles, and any other foreign matter that might happen to be in the crankcase. These materials when present in the lubricating oil cause excessive engine wear due to abrasion. The use of an efficient oil filter will, to some extent, minimize the circulation of these undesirable substances, but some of the particles, although large enough to interfere with satisfactory operation, readily pass through the openings in the filter. The only safe way to insure freedom from this injurious effect of sludge in the oil, as well as the others mentioned previously, is to use an oil which is highly resistant to oxidation.

Investigators have found that oils which show an asphaltene formation of not more than 10 mg./10 g. oil in 72 hours in the laboratory apparatus will be practically sludge-free in engine operation. Generally speaking, the sludge formation in an engine is greater than the formation in the laboratory apparatus.[27] Doubtless the rate of sludge formation is accelerated by the catalytic effect of the metal of the engine in contact with the oil.

Despite the increasing importance that has been attached to the oxidation stability of motor oils in the past few years, very little information of real value regarding this property has been made available in the technical literature. It was hoped at the beginning of this investigation that it might result in the revelation of some relation which might exist between the oxidation stability and other properties of the oil, the determination of which are less time-consuming and require less elaborate equipment than does the Indiana oxidation test. The findings, though meager and far from what might be desired, are included in this discussion.

It was observed that those oils which have a high API gravity are far more resistant to oxidation than those oils of lower gravity. This is in accordance with what might be expected since a high API gravity indicates the presence

Laboratory Data

Sample	Gravity Deg. API	Corrosion	ASTM Color	Neutralization No.	Carbon Residue Per Cent	Flash Point Deg. F.	Fire Point Deg. F.	Cloud Point Deg. F.	Pour Point Deg. F.	Viscosity at 210° F. Seconds	Viscosity at 130° F. Seconds	Viscosity at 100° F. Seconds	Viscosity Index	Sludge at 24 hr.	Sludge at 48 hr. Mg./10g. Oil	Sludge at 72 hr.	Viscosity After 50 hr. Oxidation Sec. at 210° F.
1a	19.0	N	4—	.05	.08	385	450	NO	—0	48.9	150	344	30	88	453	622	89.2
2a	29.8	S	5	.02	.17	450	490	34	25	52.4	146	302	93	17	57	86	59.5
4a	25.2	N	3½	.04	.08	415	465	NO	—0	49.1	145	311	52	29	130	200	60.5
5a	25.7	N	6+	.04	.52	425	465	24	25	55.7	184	418	78	79	193	273	72.9
7a	28.2	S	3+	.02	.04	405	460	18	—0	51.6	149	310	89	2	13	53	55.0
9a	31.3	N	2	.02	.10	425	490	26	—0	62.2	186	385	119	1	3	17	69.5
10a	23.5	N	4½	.03	.10	375	425	42	—0	50.9	150	328	70	117	226	294	73.9
11a	29.5	N	2	.01	.02	420	490	18	—0	54.0	160	340	93	*	*	*	65.3
12a	24.7	N	2	.03	.02	380	420	NO	—0	51.0	143	300	85	9	60	110	53.3
14a	30.2	N	5+	.02	.31	425	480	30	—0	59.8	182	366	117	2	3	62	66.7
15a	29.7	N	7	.03	.63	405	470	44	—0	59.3	174	348	118	3	9	48	68.1
16a	26.4	N	4+	.02	.23	410	475	10	—0	56.1	173	363	98	23	99	181	67.1
17a	26.4	N	4½	.02	.26	400	475	NO	5	58.0	190	416	92	29	122	191	68.8
18a	29.1	N	5	.03	.24	400	470	18	—0	52.4	137	272	108	4	40	94	58.1
20a	26.9	N	5	.03	.27	415	470	14	—0	54.8	175	391	80	12	74	167	63.8
21a	26.9	N	5	.04	.28	420	465	38	30	57.8	178	370	107	13	91	186	59.5
22a	28.9	N	4½	.04	.38	415	490	22	5	58.2	172	355	112	5	20	102	61.9
23a	31.5	N	5	.03	.29	425	465	40	—0	57.7	165	327	120	*	*	*	59.3
25a	28.9	N	3½	.04	.17	450	500	20	10	57.3	170	359	105	2	15	60	64.3
26a	24.3	N	6	.07	.26	375	415	22	—0	57.8	190	416	92	24	119	245	67.4
27a	28.4	N	2½	.03	.06	405	460	20	—0	62.7	188	373	125	17	59	100	71.0
29a	23.2	N	4½	.03	.04	385	430	NO	—0	49.8	141	307	69	45	134	211	57.3
30a	28.4	N	7	.03	.49	405	475	34	—0	61.7	207	467	99	2	13	47	72.5
31a	29.1	N	7	.02	.33	450	495	20	20	57.3	175	371	101	21	50	136	70.5
35a	32.0	N	5	.02	.23	415	475	30	25	49.4	125	245	96	7	32	93	56.3
38a	25.5	N	6	.04	.80	395	455	22	20	64.1	251	600	84				
39a	26.6	N	5	.04	.40	425	490	36	30	57.8	176	370	107	5	14	47	60.0
41a	29.5	N	5	.02	.45	425	475	50	20	54.7	158	322	107	7	12	47	62.4
42a	19.5	N	6	.06	.06	385	415	NO	5								
43a	25.4	N	6	.03	.29	415	470	16	—0	51.7	140	284	102	2	27	80	58.8
44a	19.7	N	5	.04	.06	390	420	NO	—0	54.0	206	531	13				
45a	26.1	N	7	.03	.49	410	475	22	10	56.4	186	421	77	68	185	322	72.2
46a	28.9	N	6	.02	.44	430	485	32	25	61.2	200	439	101	1	2	20	58.8
49a	27.3	N	5	.04	.33	420	460	28	30	49.8	140	295	76	15	87	191	57.1
50a	29.5	N	6	.02	.45	425	480	38	—0	56.3	169	355	100	3	14	48	61.6
51a	29.3	N	5	.05	.36	425	470	16	5	53.3	150	302	102	9	19	57	57.8
54a	26.9	N	4½+	.03	.27	415	470	24	—0	53.1	160	349	80	1	19	90	55.7
56a	21.8	N	6	.05	.27	380	440	NO	—0	53.2	178	413	46	133	476	578	90.2
57a	28.9	N	5+	.03	.32	410	480	18	—0	54.3	158	323	100	8	44	108	59.5
58a	25.0	N	5	.04	.16	385	435	NO	—0	54.0	195	492	29	54	208	365	68.1
60a	26.6	S	7	.05	.37	415	470	18	10	59.6	190	411	104	22	81	185	66.2
61a	25.2	N	6	.06	.22	405	465	36	—0	51.1	145	313	78	74	245	451	63.4
62a	28.6	P	7	.03	.68	430	490	22	20	68.5	250	560	105	4	8	18	82.5
63a	30.0	P	5	.02	.30	425	485	20	10	54.3	155	318	102	2	10	26	57.0
65a	26.8	P	5	.05	.30	410	460	26	15	53.5	160	335	95	8	59	124	57.8
70a	27.1	P	6	.03	.33	410	460	12	—0	54.9	170	367	89	30	132	286	64.3
72a	26.4	P	7	.04	.69	380	435	22	15	55.4	178	387	81	50	230	417	67.6
77a	30.4	S	7	.03	.38	435	490	28	25	59.1	188	405	101	5	14	43	62.8
78a	20.8	P	3½	.04	.03	330	385	NO	—0	49.2	146	333	37	35	143	294	60.4

Sample	Gravity Deg. API	Corrosion	ASTM Color	Neutralization No.	Carbon Residue Per Cent	Flash Point Deg. F.	Fire Point Deg. F.	Cloud Point Deg. F.	Pour Point Deg. F.	Viscosity at 210° F. Seconds	Viscosity at 130° F. Seconds	Viscosity at 100° F. Seconds	Viscosity Index	Sludge at 24 hr.	Sludge at 48 hr. Mg./10g. Oil	Sludge at 72 hr.	Viscosity After 50 hr. Oxidation Sec. at 210° F.
1b	18.4	S	4	.04	.22	435	500	NO	—0	60.3	258	659	34	105	444	691	85.7
2b	28.9	N	5+	.02	.43	450	500	32	25	60.8	200	423	105	3	16	48	65.7
3b	25.2	N	7+	.01	.42	415	460	28	25	56.7	190	429	81	111	322	560	72.9
4b	24.2	N	4½	.03	.43	430	475	NO	—0	62.0	250	580	70	15	156	364	77.0
5b	25.0	N	8—	.01	.88	425	470	30	25	65.7	235	614	69	70	267	589	86.9
6b	25.2	N	7	.03	.68	410	470	30	25	57.7	200	454	80	84	233	408	74.2
7b	27.7	N	4	.01	.20	430	490	16	—0	64.5	250	571	88	*	*	*	65.8
9b	30.8	P	2½	.02	.14	435	505	12	—0	61.8	210	518	109	*	*	*	72.0
10b	23.0	N	6—	.06	.35	385	460	38	—0	63.6	270	683	58	17	174	345	79.1
11b	28.9	N	2	.01	.08	455	510	12	—0	62.6	226	511	92	*	*	*	62.9
12b	21.1	N	2	.04	.10	400	445	10	—0	56.2	225	571	22	12	175	289	66.5
13b	21.5	N	6	.05	.24	375	420	22	—0	58.4	235	584	71	22	160	307	72.5
14b	29.8	N	6	.03	.52	435	490	36	—0	67.1	240	510	108	*	*	*	74.6
15b	29.1	N	7	.03	.82	415	465	52	—0	60.3	168	419	102	3	8	32	66.5
16b	25.7	N	5	.03	.60	430	490	NO	5	62.5	240	565	79	10	73	136	69.6
17b	25.9	N	6	.03	.60	425	495	NO	—0	64.7	255	583	85	39	100	207	71.6
18b	28.4	N	7	.03	.62	420	485	24	—0	61.4	213	464	95	8	10	30	67.4
19b	17.6	N	4D	.14	.26	320	350			57.4	275	796	—43	117	423	723	
20b	25.9	N	6	.02	.60	420	480	22	—0	61.8	239	566	74	5	66	180	69.6
21b	25.9	N	6	.02	.65	425	485	32	30	63.6	250	598	77	7	80	228	71.8
22b	28.2	N	5+	.02	.62	435	490	22	5	64.0	230	503	98	5	7	26	71.5
23b	29.1	P	5	.02	.23	435	490	42	5	67.5	258	582	97	*	*	*	69.8
25b	28.0	N	4+	.03	.32	445	500	20	5	62.2	228	509	113	9	20	56	66.8
26b	23.8	N	6—	.03	.30	410	465	30	—0	63.3	293	785	51	14	56	131	70.5
28b	23.1	N	6	.13	.19	380	440	32	—0	57.7	220	526	57	48	171	214	70.6
29b	22.0	N	4½	.03	.08	400	450	NO	—0	55.8	210	526	38	38	138	322	65.7
30b	28.6	N	7	.03	.68	435	490	40	—0	68.7	250	550	104	5	5	18	74.5
31b	29.1	N	7	.04	.57	435	495	40	5	64.1	223	490	101	7	15	70	73.0
34b	27.1	N	5+	.03	.33	375	420	32	25	47.1	115	225	83	39	178	344	63.8
35b	29.5	N	6	.03	.54	410	465	40	10	57.9	158	368	107	3	12	43	62.8
36b	18.7	N	8+	.14	.29	305	335	40	—0	49.7	170	430	—5	71	402	728	101.8
39b	29.5	N	6+	.03	.57	435	490	42	30	62.8	210	449	107	12	11	36	68.7
40b	19.7	N	5	.05	.09	380	410	16	5	52.3	212	645	—76	84	259	408	68.9
41b	28.9	N	6+	.02	.72	435	480	54	25	61.0	202	438	101	8	8	43	66.7
42b	18.9	N	7	.05	.08	395	435	NO	5	56.0	250	681	—18				
43b	28.6	N	6+	.01	.50	425	485	30	—0	58.8	190	407	100	1	12	50	66.0
45b	25.7	N	6+	.03	.66	420	480	24	10	64.7	240	596	82	53	170	305	77.1
46b	27.8	N	7	.03	.91	450	510	34	25	76.2	315	719	100	*	*	*	96.0
47b	18.9	N	8	.10	.41	295	315	NO	—0	47.8	150	358	—2	122	369	769	87.3
49b	25.0	N	6	.01	.64	425	475	36	20	61.7	240	556	76	30	187	368	72.8
50b	28.4	N	6	.03	.79	435	480	42	30	69.0	246	535	109	*	*	*	78.0
51b	29.3	N	6—	.03	.68	435	480	30	—0	64.7	190	481	107	*	*	*	72.1
53b	25.7	N	6	.02	.56	435	480	20	10	61.3	320	488	88	24	102	217	68.6
54b	25.7	P	5+	.02	.54	425	480	24	10	64.5	250	560	90	23	31	118	70.7
56b	21.3	N	5+	.03	.36	410	450	NO	—0	57.0	181	489	61	24	189	465	79.6
57b	28.2	P	7	.02	.58	435	485	24	5	64.4	227	491	101	2	9	28	68.5
58b	20.8	N	6	.02	.58	380	445	NO	—0	66.0	286	731	59	26	219	457	98.9
60b	28.2	N	7	.04	.73	425	485	30	5	65.8	233	500	107	5	12	50	57.6
61b	24.2	N	6	.02	.41	405	470	34	15	61.8	190	494	86	77	228	484	75.3
62b	28.7	N	6+	.03	.66	430	480	26	20	67.0	240	521	106	4	5	23	76.1
63b	29.8	N	6	.02	.51	435	490	22	10	64.5	231	501	103	*	*	*	68.8

Sample	Gravity Deg. API	Corrosion	ASTM Color	Neutralization No.	Carbon Residue Per Cent	Flash Point Deg. F.	Fire Point Deg. F.	Cloud Point Deg. F.	Pour Point Deg. F.	Viscosity at 210° F. Seconds	Viscosity at 130° F. Seconds	Viscosity at 100° F. Seconds	Viscosity Index	Sludge at 24 hr.	Sludge at 48 hr. Mg./10g. Oil	Sludge at 72 hr.	Viscosity After 50 hr. Oxidation Sec. at 210° F.
65b	26.4	N	6	.04	.53	420	475	32	15	61.7	220	485	94	2	22	55	66.5
66b	20.6	N	5	.03	.06	360M	415	64	—0	48.7	149	342	31	76	220	311	56.1
67b	20.0	N	6	.02	.17	375M	425	58	—0	55.9	219	542	33	105	250	427	69.8
68b	24.3	N	7+	.06	.71	390	420	30	20	56.0	190	431	73	56	237	544	71.9
69b	18.2	N	5+D	.12	.57	315M	325	TD	—0	54.7	230	629	—13	272	758	1446	144.0
70b	24.9	N	6	.02	.56	420	480	32	—0	60.2	220	500	79	37	188	359	71.5
71b	20.0	N	4½+	.03	.07	380	435	52	—0	53.5	200	502	25	81	223	406	62.3
72b	25.4	N	7	.01	.84	380	435	30	20	59.0	200	443	90	16	192	440	74.5
73b	25.6	N	6	.02	.81	405	465	44	—0	64.5	246	578	86	17	141	227	75.2
74b	20.2	N	4—D	.08	.23	300	345	NO	—0	47.0	135	303	18	99	254	495	70.7
76b	18.2	N	5—D	.14	.60	300	345	TD	—0	47.9	148	346	7	179	550	1044	93.4
77b	29.3	N	7	.02	.56	445	490	34	25	66.7	232	492	112	2	7	30	71.8
79b	19.8	S	4½D	.11	.57	330	360	NO	—0	50.6	159	367	48	87	334	813	82.1
82b	30.0	N	6	.02	.49	430	490	42	—0	63.5	184	445	112	*	*	*	66.4
1c	18.4	N	6—	.03	.68	460	530	NO	5	72.3	356	933	53	116	561	896	121.2
2c	27.8	N	7	.02	.76	460	505	34	25	71.8	285	581	110	2	7	38	82.7
3c	24.2	N	8	.03	.89	445	475	30	25	67.3	280	637	79	56	270	427	83.8
4c	23.8	N	5	.03	.52	440	500	NO	—0	69.4	313	771	68	5	125	308	82.5
5c	24.3	N	8	.03	1.00	435	475	38	25	69.8	297	700	83	34	192	374	89.0
6c	24.5	N	8	.02	.94	425	470	36	25	66.7	265	626	85	71	243	445	92.0
7c	27.3	N	4½	.02	.23	440	500	16	—0	71.8	295	665	96	*	*	*	75.5
8c	21.1	N	6—	.03	.09	195	320	NO	—0	49.6	145	323	59	160	430	791	107.0
9c	30.6	N	3	.02	.14	450	505	NO	—0	72.8	273	587	111	*	*	*	78.2
10c	22.6	N	6	.03	.42	420	475	58	—0	69.4	305	772	66	13	131	298	88.6
11c	28.2	N	2+	.01	.10	480	545	NO	5	73.0	295	689	96	*	*	*	72.4
12c	20.5	N	3	.04	.16	415	470	NO	—0	66.5	331	915	76	14	165	310	80.7
13c	20.6	N	5	.03	.22	395	345	20	—0	73.5	320	760	88	24	176	291	78.0
14c	29.5	N	6+	.01	.70	440	495	38	—0	72.9	272	601	109	*	*	*	84.2
15c	28.4	N	7	.01	.99	430	490	52	—0	69.2	258	568	103	*	*	*	78.5
16c	24.7	N	5+	.02	.69	445	500	NO	—0	72.4	315	762	81	12	116	263	87.0
17c	25.6	N	4½	.02	.57	440	495	NO	—0	75.2	310	712	98	8	74	205	93.0
18c	27.7	N	7	.02	.69	435	495	20	10	75.7	307	686	104	*	*	*	85.6
19c	18.2	N	8	.13	.20	375	430	NO	10	73.5	296	932	63	165	458	748	95.0
20c	25.6	N	6	.02	.67	435	480	20	5	66.4	296	702	65	2	52	173	76.3
21c	24.8	N	6	.01	.75	440	490	34	20	73.6	320	787	84	1	50	205	86.5
22c	27.7	N	6—	.02	.77	435	495	20	5	73.3	293	660	100	*	*	*	82.0
23c	29.3	N	5	.02	.24	435	485	44	5	68.9	255	571	103	*	*	*	70.4
24c	26.4	N	4D	.04	.50	405	475	TD	—0	66.0	240	532	100	7	45	141	66.8
25c	26.8	N	5	.10	.39	460	525	34	5	69.5	280	649	92	2	15	71	79.0
26c	24.2	N	5	.04	.37	385	460	20	—0	68.1	290	694	76	12	86	144	81.6
27c	29.5	S	5	.01	.29	425	480	32	—0	100.6	410	873	122	*	*	*	98.1
28c	21.0	N	5	.03	.12	400	455	22	—0	61.8	280	740	30	13	164	287	77.2
29c	20.1	N	8	.08	.13	420	465	22	5	63.6	308	854	19	27	190	328	79.5
30c	28.2	N	8	.02	.76	445	490	34	—0	74.9	300	672	104	*	*	*	83.4
31c	28.4	N	7	.04	.78	450	500	38	25	73.0	283	633	104	4	12	60	88.3
32c	18.1	S	4—D	.12	.19	285	320	TD	—0	51.0	200	549	—51				
33c	22.8	N	8	.02	1.01	395	460	50	20	77.4	372	962	70				
34c	25.7	N	6	.03	.49	400	455	32	20	56.5	187	413	90	73	303	619	74.0
35c	28.6	N	7	.03	.69	430	480	40	30	66.9	240	525	105	1	4	29	73.8

Sample	Gravity Deg. API	Corrosion	ASTM Color	Neutralization No.	Carbon Residue Per Cent	Flash Point Deg. F.	Fire Point Deg. F.	Cloud Point Deg. F.	Pour Point Deg. F.	Viscosity at 210° F. Seconds	Viscosity at 130° F. Seconds	Viscosity at 100° F. Seconds	Viscosity Index	Sludge at 24 hr.	Sludge at 48 hr. Mg./10g. Oil	Sludge at 72 hr.	Viscosity After 50 hr. Oxidation Sec. at 210° F.
36c	17.1	N	8	.06	.19	300	355	NO	5	61.3	340	1084	—70	175	432	746	104.1
37c	25.7	N	7—	.02	.65	425	480	30	15	65.1	265	630	75	7	87	353	75.9
38c	25.6	N	6+	.04	.74	405	455	42	25	64.6	258	603	81	7	115	346	74.7
39c	28.8	N	7	.01	.76	445	500	40	35	75.2	300	669	104	*	*	*	81.0
40c	19.2	N	5+	.05	.09	380	440	NO	5	60.1	280	768	4	76	256	424	79.4
41c	28.0	S	7—	.01	1.00	445	495	54	30	77.2	328	748	98	*	*	*	89.6
42c	17.6	N	7	.06	.19	425	465	NO	10	70.6	425	1308	—14	142	289	517	95.9
43c	28.0	N	7	.01	.76	440	485	26	5	72.6	280	639	103	*	*	*	84.1
46c	27.7	N	7	.01	1.03	450	520	42	20	86.0	395	957	95	*	*	*	100.5
48c	24.5	N	7	.05	.67	400	450	52	20	63.9	240	614	73				
49c	25.0	N	7+	.04	.82	420	475	50	30	68.6	260	589	100	11	135	282	82.3
50c	28.2	N	7	.01	.80	430	490	40	30	74.9	300	686	102	*	*	*	86.4
51c	28.2	N	6	.01	.73	430	485	28	15	71.0	280	628	99	*	*	*	79.0
52c	23.5	N	8	.08	.51	375	410	50	—0	60.6	238	555	70	105	454	765	96.0
53c	24.8	N	6	.03	.80	430	495	34	5	71.1	310	757	78	20	131	283	87.1
54c	26.1	N	6	.01	.65	440	495	32	20	71.7	305	738	85	2	2	39	78.3
55c	19.5	N	6	.03	.16	395	455	46	5	62.9	315	900	—1	56	164	427	76.3
56c	21.1	N	7	.07	.60	415	475	30	—0	64.1	300	828	25	24	189	532	85.9
57c	27.7	N	8	.05	.94	435	485	NO	10	72.8	300	680	97	1	2	21	90.8
58c	21.0	N	7	.03	.89	400	460	16	—0	78.9	400	1073	63	16	143	461	105.0
59c	16.5	N	6	.16	.18	380	445	38	10	67.2	380	1160	—20	83	392	700	110.1
60c	23.6	N	7	.05	.55	410	475	42	10	68.2	280	662	82	8	60	153	80.2
62c	27.0	N	7	.04	.88	435	495	36	20	80.6	355	845	96	*	*	*	96.0
63c	28.4	S	6	.02	.68	445	505	38	20	71.8	270	595	107	*	*	*	80.0
64c	24.3	N	6+	.01	1.01	380M	435	54	25	65.7	258	591	88	20	154	676	89.9
65c	27.0	N	6	.03	.57	420	485	36	15	68.9	263	589	100	*	*	*	77.3
66c	19.5	N	6—	.06	.10	365	420	64	—0	56.1	238	616	6	82	214	579	70.6
67c	19.5	N	6	.04	.17	390	435	88	5	59.3	259	676	20	113	305	569	78.2
68c	23.8	N	7+	.03	.83	395	450	32	25	68.4	290	698	76	6	192	414	91.5
69c	18.1	N	6—D	.03	.63	290	345	TD	—0	53.2	195	495	—2	217	573	1285	109.0
70c	24.7	N	6	.01	.78	430	495	36	5	69.5	300	746	76	13	152	323	88.3
71c	19.3	N	5	.02	.07	400	435	60	5	56.6	255	697	—10	76	227	276	69.0
72c	24.8	N	7	.03	.86	400	430	34	20	61.1	230	522	79	13	178	432	74.8
73c	25.4	N	6	.04	.97	435	475	38	—0	73.0	320	767	84	10	145	301	92.6
74c	17.6	N	5+D	.20	.67	305	345	TD	—0	51.2	180	449	4	174	625	867	106.9
75c	19.3	N	5+D	.18	.55	310	355	TD	—0	52.8	185	493	13	185	694	1266	97.3
76c	17.6	N	5+D	.10	.78	315M	365	TD	—0	53.8	210	542	8	262	693	1122	121.1
77c	28.7	N	8	.02	.75	455	505	40	25	74.1	290	641	105	7	9	51	84.6
78c	20.5	N	4½	.02	.16	365	410	NO	—0	59.1	240	591	45	36	190	368	82.1
80c	18.5	N	5	.04	.12	370	425	88	—0	57.1	245	648	7	107	385	565	82.7
81c	19.5	N	4½	.04	.13	365	415	NO	—0	54.0	278	608	—20	77	225	442	70.3
83c	24.0	N	8	.03	.94	405	470	36	25	64.5	285	709	58	92	323	624	67.0
84c	17.0	N	5+D	.02	.73	325M	355	TD	—0	52.2	198	509	—9	218	608	1276	115.3

of a high percentage of paraffin hydrocarbons which are more stable compounds than those hydrocarbons belonging to the naphthenic, or asphaltic, series. In only a few cases did the sludge formation exceed 110 mg./10 g. oil in 72 hours for oils which had API gravities greater than 28.0. Among the oils whose gravities were greater than 29.0, no cases of excessive sludging were observed. Exactly as might be anticipated, a rough parallelism to this relationship between gravity and the resistance to oxidation is found in the relationship of the viscosity index and the resistance to oxidation. It is believed that this relation between viscosity index and oxidation stability is not so valuable as the relation involving gravity since there is more difficulty and less accuracy inherent to the determination of viscosity index than to the determination of gravity.

A study of the results obtained from the oxidation test reveals that those oils which show a sludge formation of less than 110 mg./10 g. oil in 72 hours generally exhibit increased resistance to oxidation with an increase in viscosity number. The converse is true for a majority of those oils which undergoe excessive sludging; that is, they show a marked decrease in resistance to oxidation in the higher viscosity grades. It must be pointed out that the frequency of exceptions to the last generalization is considerably higher than the variations from the former. No satisfactory explanation for this observed phenomenon is readily apparent in the light of this investigation, but it is quite likely that further work may clarify this observation.

With only one exception, the samples of motor oil tested show an increase in viscosity upon oxidation. Roughly speaking, the increase is related to the extent of sludge formation, but no definite relationship is discernible. The single sample, 27c, which exhibited a slight decrease in viscosity yielded practically no sludge upon oxidation. While such is not likely, there is a remote possibility that the period of time utilized in the test was sufficiently long to permit cracking to a small degree even at the relatively low temperature of 172° C.

The Indiana oxidation test is of inestimable worth in evaluating an oil that is to be used as a crankcase lubricant. The data obtained in this investigation indicate that oils which undergo sludging only to a slight degree also have other properties desirable in motor lubricants, such as high viscosity index and high flash point without excessive carbon residue. Unfortunately it does not follow that oils which possess these properties give low sludge values. In the light of this finding, the writer is of the opinion that the results obtained from the Indiana oxidation test are of vastly more importance than the results of any single laboratory method yet employed in the testing of motor oils.

Tabulation of Laboratory Data

To facilitate the concise tabulation of the numerous experimental data obtained in this investigation, the use of symbolism in the tabulation was requisite. The meanings of the various abbreviations and symbols used are given below.

In the column headed *Corrosion,* one of three letters is found. The letter *N* indicates that the sample was reported negative in the corrosion test. *S* indicates that the sample was slightly corrosive as evidenced by a very slight discoloration of the copper test strip. *P* indicates that the sample was reported positive.

The letter *D* following the ASTM color indicates that dilution of the sample of oil was necessary in order to determine its color in the ASTM Union Colorimeter. The dilution contained 15 per cent (by volume) oil and 85 per cent benzene.

The letter *M* following the Flash Point indicates that moisture was found in the sample.

The symbol *NO* in the Cloud Point column indicates that no cloud was observed down to 0° F., the lowest temperature employed in the test. *TD* indicates that the sample was too dark to attempt a cloud point determination.

Those samples which were still fluid at 0° F. are marked —*0* in the *Pour Point* column.

The asterisks in the columns headed *Sludge* indicate that the sludge concentration at the end of the 72-hour test period was less than 15 mg./10 g. oil. The blanks that occur in these columns are occasioned by the fact that not all of the samples were available for the oxidation test.

CONCLUSIONS

In order to facilitate the formation of correct conclusions from the laboratory data obtained in this investigation certain condensed tabulations are convenient.

From the beginning it was suspected that there are considerable differences existing between the physical properties of oils that are marketed in refinery-sealed cans and the properties of oils sold in bulk. Certainly those oils sold in cans are not so likely to be degraded by careless handling after completion of the refining process as are the bulk oils. The basis of comparison used was the specifications given in Federal Standard Stock Catalogue, Sec. IV, VV–0–496. The limiting requirements are summarized below.

The Federal Specifications Board require that the samples of motor oils contain no moisture, or corrosive materials detectable by the copper strip test, and that the neutralization number be less than 0.30. The limitations imposed on the viscosity of the oils corresponding to various SAE numbers are given below.

	Saybolt Universal Viscosity			
	Seconds at 130° F.		Seconds at 210° F.	
SAE Number	Not less than	Less than	Not less than	Less than
20	120	185	------	------
30	185	255	------	------
40	255	------	------	75
50	------	------	75	105

Other limitations imposed on flash point, pour point, color, and carbon residue are listed in the table which follows.

SAE Number	Minimum Flash Point Deg. F.	Maximum Pour Point Deg. F.	Darkest ASTM Color	Maximum Carbon Residue Per Cent
20	340	40	7½	0.60
30	350	40	8	0.80
40	370	40	6D	1.00
50	395	40	7D	1.40

It will be noticed from the tabulation of the laboratory data that none of the samples exceed the limits on pour point, color, or neutralization number. The few cases of

excessive carbon residue are not considered in view of the fact that there is definite evidence that certain oils which give reliable indications of being good oils—namely, high resistance to oxidation, high gravity, and high viscosity index—may have even higher carbon residues than do oils known to be very poor in quality. Since it must be admitted that the viscosities at 130° F. as determined by means of the ASTM Viscosity-Temperature Chart are not absolutely accurate, a margin of ± 1 per cent was allowed in comparing the viscosities of the samples with the limits of the specifications. For example, an oil sold as SAE 20, but which has a viscosity of 187 seconds at 130° F. would be passed; similarly, an oil sold at SAE 30 with a viscosity of 183 seconds at 130° F. would also be passed.

TABLE I

NUMBER OF SAMPLES, CLASSIFIED ACCORDING TO SAE NUMBER AND TYPE OF PACKAGING, FAILING TO MEET REQUIREMENTS OF FEDERAL SPECIFICATIONS BOARD

SAE Number	Viscosity High		Viscosity Low		Flash Low		Moisture		Corrosion	
	Cans	Bulk	Cans	Bulk	Cans	Bulk	Cans	Bulk	Cans	Bulk
									3S	1S
20	4	5	----	----	----	----	----	----	4P	2P
									1S	1S
30	1	3	3	7	----	7	----	4	4P	—
									1S	2S
40	----	3	2	14	----	11	----	3	—	—
									5S	4S
Total	5	11	5	21	----	18	----	7	8P	2P
									9S	
Grand Total	16		26		18		7		10P	

Samples 27a, 27c, 46a, 46b, and 46c were not sold by SAE numbers, so are not included in the above tabulation.

Not all the data on the viscosity of sample 42a is available, so this sample is not included in the above tabulation.

Even a casual study of Table I will serve to indicate the decided advantages to be gained by purchasing motor oils in sealed containers rather than in bulk.

The few instances in which those oils marketed in sealed containers failed to meet the viscosity requirements were border-line failures, which are far less objectionable than

TABLE II

NUMBER OF SAMPLES, CLASSIFIED ACCORDING TO SAE NUMBER AND PRICE, FAILING TO MEET REQUIREMENTS OF FEDERAL SPECIFICATIONS BOARD

Cost Per Quart	SAE Number	Viscosity High	Viscosity Low	Flash Point Low	Moisture	Corrosion
Above 30c	20	4	----	----	----	3S 2P
	30	----	1	----	----	— 3P
	40	----	----	----	----	1S —
Total		4	1	----	----	4S 5P
25c–29c	20	3	----	----	----	1S 3P
	30	2	2	----	----	1S 1P
	40	1	2	----	----	— 2S
Total		6	4	----	----	4P
Under 24c	20	2	----	----	----	— 1P
	30	2	7	7	4	1S —
	40	2	14	11	3	2S —
Total		6	21	18	7	3S 1P
Grand Total		16	26	18	7	9S 10P

Samples 27a, 27c, 46a, 46b, and 46c were not sold by SAE numbers, so are not included in the above tabulation.

Not all the data on the viscosity of sample 42a is available, so this sample is not included in the above tabulation.

the marked variations from specifications observed in the bulk oils. It is to be said that—generally speaking—the viscosities of those oils delivered to the purchaser in refinery-sealed containers satisfactorily conform with the SAE numbers specified by the purchaser; however, in the case of oils sold in bulk, such is not true.

It will be noticed that no cases of oils having low flash points or containing moisture were observed in samples sold in cans. Several of the bulk samples contained considerable portions of volatile material. These samples are

to be suspected of being crankcase drainings which may or may not have been filtered before being resold. It is possible to re-refine such drainings and obtain an excellent lubricant, but the treatment required would involve, in addition to filtration to remove sludge and sediment, distillation to remove the heavy gasoline fractions and water, and an acid-clay treatment. While it is not to be inferred that even a majority of bulk oils are to be suspected as being crankcase drainings, it must be recognized that there is a vastly greater possibility of receiving such material when motor oils are purchased in bulk rather than in cans.

A word of explanation in regard to the results of the corrosion test is believed necessary at this point. While 19 cases of positive or slight corrosions, a majority of which occurred in samples of canned oil, may seem to be a rather large number, it will also be noted that no two samples of the same oil were found to be corrosive; which indicates that the cases of corrosion observed were probably due to an occasional discrepancy in the refining process. Such variations are liable to occur at odd intervals even when extreme care in both refining and testing the products is exercised. While the number of such cases encountered in this work is higher than should be expected, no great alarm should be caused by this since, as already mentioned, the test is of slight importance.

Table II indicates that as the price paid for motor oils increases there is a marked decrease in the number of failures to meet specifications. It is to be expected that those oils which sell for the higher prices would receive more careful handling and treatment in the refining process. The chances for contamination and resulting failures to meet the requirements of the Federal Specifications Board are further minimized in the case of most of the oils selling for 25c or more per quart by being marketed in refinery-sealed containers.

Many of the oils which satisfactorily meet the minimum requirements of the Federal Specifications Board would be far from satisfactory in actual service as indicated by

results of the Indiana oxidation test. In an effort to obtain a basis for classifying the oils according to actual service performance that might be expected, rather severe limitations were imposed on certain properties—oxidation stability, viscosity index, pour point, and Conradson carbon residue—considered by automotive engineers as being of considerable importance in predicting the real merit of oils.

The significance of each of the four properties chosen as the basis for classification has been discussed previously. The results of the Indiana oxidation test serve as the principal basis of differentiation, since the oils are rather sharply divided into two groups—oils which undergo sludging only to a small degree and those which sludge heavily. The property considered next in importance is the viscosity index. It was found that those oils which fall in the first mentioned group have rather high viscosity indices, while among those that are included in the latter there is a decided trend toward the lower side of the viscosity index scale. In view of the fact that the oils studied in this investigation were refined for use in a climate usually free from extremely low temperatures rather liberal limitations were imposed on the pour point. Less attention is accorded the limits on the Conradson carbon residue than any of the other properties utilized in this basis of comparison.

The requirements for classification of the various oils as superior, satisfactory, or poor are tabulated below.

	Sludge* Less Than	Viscosity Index Greater Than	Pour Point Less Than	Carbon Residue Less Than
SAE 20 Oils				
Superior	50 mg.	90	0° F.	0.60%
Satisfactory	110 mg.	80	32° F.	0.70%
Poor	Sludge greater than 110 mg.			
SAE 30 Oils				
Superior	50 mg.	90	10° F.	0.70%
Satisfactory	110 mg.	85	32° F.	0.90%
Poor	Sludge greater than 110 mg.			
SAE 40 Oils				
Superior	50 mg.	90	15° F.	0.70%
Satisfactory	110 mg.	85	32° F.	1.00%
Poor	Sludge greater than 110 mg.			

*The sludge is reported in milligrams of sludge formed in 72 hours per 10 grams of oil.

The properties of each of the samples were compared with the arbitrary standards listed in the table just preceding, and the results are given in the following tabulation. Those samples marked with an asterisk are classified as "Superior," or "Satisfactory," in spite of the fact that they were incorreclty marked as to SAE number by the manufacturer.

Sample	Cost per Quart Cents	Can or Bulk	Classification	Sample	Cost per Quart Cents	Can or Bulk	Classification
1a	25	C	P	38a	20	B	P
2a	35	C	S	39a	15	B	S
4a	25	C	P	41a	15	B	S
5a	30	C	P	42a	10	B	P
7a	25	C	S	43a	15	B	S
9a	35	C	Su	44a	8	B	P
10a	19	B	P	45a	25	C	P
11a	30	C	Su	46a	35	C	S
12a	25	C	S	49a	25	C	P
14a	33	C	S	50a	25	C	S
15a	30	C	Su	51a	35	C	S
16a	30	C	P	54a	25	C	S
17a	25	C	P	56a	25	C	P
18a	30	C	S	57a	30	C	S
20a	31	C	P	58a	25	B	P
21a	20	C	P	60a	30	B	P
22a	35	C	S	61a	25	C	P
23a	30	C	Su	62a	30†	B	S*
25a	33	C	S	63a	35	C	S
26a	28	C	P	65a	25	C	P
27a	36	C	S	70a	25	C	P
29a	20	B	P	72a	25	C	P
30a	35	C	Su*	77a	30	C	S*
31a	30	C	P	78a	15	B	P
35a	25	C	S				
1b	25	C	P	19b	15	B	P
2b	35	C	S	20b	31	C	P
3b	20	C	P	21b	25	C	P
4b	25	C	P	22b	35	C	Su
5b	30	C	P	23b	30	C	S
6b	25	C	P	25b	33	C	S
7b	25	C	S	26b	28	C	P
9b	35	C	S	28b	16	B	P
10b	19	B	P	29b	20	B	P
11b	30	C	Su	30b	35	C	Su
12b	25	C	P	31b	30	C	S
13b	15	B	P	34b	15	B	P
14b	33	C	Su	35b	25	C	S*
15b	30	C	S*	36b	10	B	P
16b	30	C	P	39b	15	B	S
17b	25	C	P	40b	12	B	P
18b	30	C	Su	41b	15	B	S

†Sold to "special customers" for 5c per quart, according to vendor.

Sample	Cost per Quart Cents	Can or Bulk	Classification
42b	10	B	P
43b	15	B	P
45b	25	C	P
46b	35	C	S
47b	10	B	P
49b	25	B	P
50b	25	C	S
51b	35	C	Su
53b	25	B	P
54b	25	C	P
56b	25	C	P
57b	30	C	P
58b	25	B	P
60b	30	B	S
61b	25	C	P
62b	30†	B	S
1c	25	C	P
2c	35	C	S
3c	20	C	P
4c	25	C	P
5c	30	C	P
6c	25	C	P
7c	25	C	Su
8c	15	B	P
9c	35	C	Su
10c	19	B	P
11c	30	C	Su
12c	25	C	P
13c	15	B	P
14c	33	C	Su
15c	30	C	S
16c	30	C	P
17c	25	C	P
18c	30	C	Su
19c	15	B	P
20c	31	C	P
21c	20	C	P
22c	35	C	S
23c	30	C	Su
24c	10	B	P
25c	33	C	S
26c	28	C	P
27c	36	C	Su
28c	16	B	P
29c	20	B	P
30c	35	C	S
31c	30	C	S
33c	20	B	P
34c	15	B	P
35c	25	C	S*
36c	20	B	P
37c	20	B	P
38c	20	B	P
39c	15	B	S
40c	12	B	P
63b	35	C	S
65b	25	C	S
66b	10	B	P
67b	15	B	P
68b	15	B	P
69b	10	B	P
70b	25	C	P
71b	5	B	P
72b	25	C	P
73b	25	C	P
74b	10	B	P
76b	10	B	P
77b	30	C	S
79b	12½	B	P
82b	30	C	Su
41c	15	B	S*
42c	10	B	P
43c	15	B	S
46c	35	C	S
48c	15	B	P
49c	25	C	P
50c	25	C	S
51c	35	C	S
52c	18	B	P
53c	25	B	P
54c	25	C	S
55c	15	B	P
56c	25	C	P
57c	30	C	S
58c	25	B	P
59c	15	B	P
60c	30	B	P
62c	30†	B	S
63c	35	C	S
64c	15	B	P
65c	25	C	Su
66c	10	B	P
67c	15	B	P
68c	15	B	P
69c	15	B	P
70c	25	C	P
71c	7½	B	P
72c	25	C	P
73c	25	C	P
74c	10	B	P
75c	15	B	P
76c	15	B	P
77c	30	C	S
78c	15	B	P
80c	12½	B	P
81c	10	B	P
83c	15	B	P
84c	10	B	P

†Sold to "special customers" for 5c per quart, according to vendor.

On the basis of this classification, Tables III and IV present condensed results parallel to those shown in Tables I and II.

Table III indicates rather clearly the greater likelihood of receiving a good lubricating oil when purchased in sealed containers rather than in bulk. It is not to be inferred that the fact that the oils are canned is responsible in entirety for the condition observed, but the better oils are marketed in refinery-sealed containers rather than in bulk.

It seems that Table IV should be entirely self-explanatory. The findings are just as would be supposed—that as the price increases, the number of good oils increases, accompanied with a corresponding decrease in the poorer oils.

TABLE III

SAE Number	Superior Cans	Superior Bulk	Satisfactory Cans	Satisfactory Bulk	Poor Cans	Poor Bulk	Total Samples Cans	Total Samples Bulk
20	5	----	14	4	16	7	35	11
30	7	----	12	5	19	21	39	25
40	7	----	13	4	16	36	36	40
Others ----	1	----	4	----	----	1	5	1
Total ------	20	----	43	13	51	65	115	77
Grand Total	20		56		116		192	

The group of oils denoted by *Others* includes samples 27a, 27c, 42a, 46a, 46b, and 46c.

TABLE IV

Cost per Quart	SAE Number	Superior	Satisfactory	Poor	Total
Above 30c----------	20	5	10	5	20
	30	7	10	4	21
	40	5	11	4	20
Others ----------		1	4	----	5
Total ----------		18	35	13	66
25c–29c ----------	20	----	5	12	17
	30	----	4	17	21
	40	2	3	13	18
Others ----------		----	----	----	----
Total ----------		2	12	42	56
Under 24c----------	20	----	3	6	9
	30	----	3	19	22
	40	----	3	35	38
Others ----------		----	----	1	1
Total ----------		----	9	61	70
Grand Total----------		20	56	116	192

The group of oils denoted by *Others* includes samples 27a, 27c, 42a, 46a, 46b, and 46c.

SUMMARY

The results obtained from this investigation indicate that, on the whole, the oils delivered in sealed containers to motorists correspond with the SAE viscosity numbers specified at the time of purchase. Those oils which are marketed in bulk—usually at a much lower price than canned oils—are not so reliable in this respect; in fact, extreme care must be exercised in purchasing bulk oils if they are to be used.

It is definitely indicated that there is a rather close relation existing between the cost and the quality of motor oils. A premium price is not an absolute assurance of receiving a premium lubricant, but it does minimize the chances for obtaining poor products. Oils sold in refinery-sealed cans for a price of 30c per quart or more may be usually expected to give satisfactory service. A few satisfactory oils were found which sell for less than 20c per quart; but, generally speaking, those oils marketed at a cost of less than 25c per quart—because of low resistance to oxidation, low viscosity index, and wide variation from the SAE viscosity number specified—will not provide reliable lubrication of modern automobile engines.

The only property of the oils that could be clearly connected with the resistance to oxidation as measured by the Indiana oxidation test was the gravity. Oils of high API gravity—indicative of high paraffinicity—were found to offer high resistance to oxidation, while those oils of low API gravity—indicating high content of naphthenic hydrocarbons—show greater tendencies toward sludging. Viscosity index is also related to oxidation stability, but, as yet, this relationship is not so clearly defined as the relation just mentioned.

An intelligent choice of a motor oil may be made upon the results of the oxidation test alone, because it has been observed that an oil which exhibits high oxidation stability also possesses the other qualities highly desirable in engine lubricants. In the case of the average car owner, one of

the most useful indications of the quality of an oil may be gained by knowing the gravity. Oils of API gravity greater than 29.0 exhibit only slight tendency toward sludging and usually have high viscosity indices.

To summarize briefly, in order to provide satisfactory lubrication of modern automobile engines under normal conditions, oils of high resistance to oxidation, high viscosity index, low pour point, and reasonably low carbon residue are required. There are satisfactory lubricants available in the cheaper grades, but it is believed that the use of motor oils sold in refinery-sealed containers at prices of 30c or more per quart will result in actual saving by reducing the likelihood of expensive repair bills that result from the use of poor lubricants.